METHOD AND APPARATUS FOR CASE HARDENING A WORK PIECE

CROSS REFERENCES TO RELATED APPLICATIONS

[0001] Not Applicable.

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH

[0002] Not Applicable.

TECHNICAL FIELD

[0003] This invention relates to case hardening gear teeth, and more particularly to a method and apparatus for case hardening gear teeth using inductive heating.

DESCRIPTION OF THE BACKGROUND ART

[0004] Gear teeth are often case hardened (i.e. the surface of the teeth are hardened to a predetermined depth) in order to provide the teeth with a hard surface to resist wear and abrasion while maintaining a root that is comparatively ductile to accommodate bending stresses. Case hardening can be accomplished by carburizing the teeth using a low carbon steel or by inductive heating.

[0005] Carburizing is a process in which carbon is diffused into the surface of gear teeth formed from a low carbon steel. The carbon is diffused into the gear teeth surface at a temperature above the transformation temperature of the steel. The teeth are quenched in oil from above the transformation temperature of the steel which causes the higher carbon surface of the teeth to harden. This process requires work pieces formed from low carbon steel, and the

quenching process can cause the work piece to deform which requires subsequent machining of the hardened surface.

[0006] Inductive heating heats a small part of a work piece using induced electrical currents. Rapid cooling of the parts of the work piece from above the transformation temperature of the work piece material hardens the part. Inductive heating and subsequent cooling of a work piece can also deform the work piece. Advantageously, inductive heating is not limited to low carbon materials, such as in the carburizing process. Inductive heating, however, requires a large amount of power to heat the work piece which can be inefficient or subject to short circuiting. Moreover, since inductive heating heats only small parts of the work piece at a time, certain thin parts of a work piece can be overheated, such as the tips of gear teeth, causing them to be too brittle. As a result, a need exists for a case hardening apparatus that does not waste electrical power and avoids overheating tips of gear teeth.

SUMMARY OF THE INVENTION

[0007] The present invention provides a method and apparatus for case hardening a work piece by inductive heating. In one embodiment of the invention, the apparatus includes a ring of conductive material having an inner diameter, an outer diameter, and opposing planar sides. Dielectric material fixed to the planar sides prevents the electrical power passing through the conductive material from short circuiting. In another embodiment of the invention, the apparatus includes a ring of conductive material having an inner diameter, an outer diameter, and opposing planar sides, and a plurality of conductive teeth extending radially from at least one of the inner diameter and the outer diameter of the ring, wherein a vertex is formed between adjacent conductive teeth, and conductive material is removed from the ring proximal the vertex to

prevent overheating gear teeth of the work piece being hardened. In yet another embodiment of the invention, the apparatus includes a ring of conductive material having an inner diameter, an outer diameter, and opposing planar sides, a plurality of conductive teeth extending radially from at least one of the inner diameter and the outer diameter, and at least one slot extending radially toward a tip of one of the teeth is formed in the conductive material to force to force the electric current closer to the teeth being hardened.

[0008] A general objective of the present invention is to provide a case hardening apparatus that can be used to case harden gear teeth of a work piece. This objective is accomplished by providing an apparatus including a ring of conductive material having an inner diameter, an outer diameter, and opposing planar sides.

[0009] Another objective of the present invention is to provide a case hardening apparatus that is not easily short circuited. This objective is accomplished by providing an apparatus including a ring having dielectric material fixed to the planar sides of the ring.

[0010] Another objective of the present invention is to provide a case hardening apparatus that does not overheat gear teeth of a work piece. This objective is accomplished by providing an apparatus including a ring having radially extending teeth that define a vertex between adjacent conductive teeth, and conductive material is removed from the ring proximal the vertex to prevent overheating gear teeth of the work piece being hardened.

[0011] Yet, another objective of the present invention is to provide a case hardening apparatus that efficiently uses electrical energy. This objective is accomplished by providing an apparatus including a ring in which at least one slot extending radially toward a tip of one of the teeth is formed in the conductive material to force to force the electric current closer to the teeth being hardened.

[0012] Yet, another objective of the present invention is to provide a method of case hardening a gear which does not require machining following hardening the case of the gear teeth. This objective is accomplished by machining the gear teeth to tolerances greater (i.e. tighter or less deviation) than that required for the finished gear prior to inductively heating and subsequent quenching of the gear teeth to form the hardened case.

[0013] The foregoing and other objectives and advantages of the invention will appear from the following description. In the description, reference is made to the accompanying drawings which form a part hereof, and in which there is shown by way of illustration a preferred embodiment of the invention. Such embodiment does not necessarily represent the full scope of the invention, however, and reference is made therefore to the claims herein for interpreting the scope of the invention.

BRIEF SUMMARY OF THE DRAWINGS

[0014] Fig. 1 is a perspective view of a case hardening apparatus incorporating the present invention;

[0015] Fig. 2 is an exploded perspective view of the apparatus of Fig. 1;

[0016] Fig. 3 is a side elevation view of the exploded view of the apparatus of Fig. 2;

[0017] Fig. 4 is a side elevation view of the apparatus of Fig. 1;

[0018] Fig. 5 is an end view of the inductor ring of Fig. 1; and

[0019] Fig. 6 is a partial end view of another inductor ring for use in a case hardening assembly incorporating the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0020] A case hardening apparatus 10, shown in Figs. 1-4, includes an inductor ring 12 sandwiched between a cooling jacket 14 and a quenching ring 16. The apparatus 10 is especially useful for inductive case of hardening radially extending gear teeth 18 of a gear 20 using a method described below. Moreover, one advantageous feature of the inductor ring 12 provides improved hardening of the gear teeth 18 without overheating the teeth tips 22 causing them to become brittle, and a second feature of the inductor ring 12 improves the efficiency of the ring.

[0021] The inductor ring 12 shown in Figs. 1-5, includes a relatively thin wafer inductor 24 formed from a conductive material, such as a metal. In a preferred embodiment shown in Fig. 5, the wafer inductor 24 is an annular sheet of copper having an inner diameter 26 and an outer diameter 28. An inner edge 30 formed at the inner diameter 26 and an outer edge 32 formed at the outer diameter 28 are joined by opposing planar sides 34, 36 to form the annular shape. In one embodiment, the copper sheet is 1/8 inch thick for use at a power level of approximately 22 kw at a frequency of approximately 4.80 khz. The thickness of the copper sheet is dependent upon the power requirements of the intended use of the inductor ring 12. Preferably, however, the copper sheet is approximately 1/8 inch thick, and no greater than ¼ inch thick .

[0022] A cut 38 extending between the inner and outer edges 30, 32 splits the inductor ring 12 to form ends 40, 42 for electrical connectors 44, 46 that supply the electrical energy to the inductor ring 12. One electrical connector 44 is electrically connected to the inductor ring 12 proximal one end 40 on one side of the cut 38, and the other electrical connector 46 is electrically connected to the inductor ring 12 proximal the other end 42 on the other side of the cut 38, such that the electrical energy flows through substantially the entire inductor 12 from the one connector 44 to the other connector 46 around the work piece being heated.

[0023] Conductive inductor teeth 48 extending radially inwardly from the inner edge 30 of the inductor ring 12 are received between the gear teeth 18 being hardened. Preferably, the inductor teeth 48 are formed as an integral part of the inductor ring 12 by forming the inductor teeth 48 and inductor ring 12 from the same sheet of conductive material. Adjacent inductor teeth 48 define a vertex 50 therebetween at the inner edge 30 of the inductor ring 12.

[0024] A hole 52 drilled at the vertex 50 removes conductive material from the inner edge 30 of the inductor ring 12 to prevent the tip 22 of each gear tooth 18 from over heating and becoming brittle. Removing the conductive material from the inductor ring 12 at each vertex 50 spaces the remaining conductive material of the inductor ring 12 further from the tips 22 of the gear teeth 18 where there is relatively little gear tooth material to heat compared to the base 54 of the gear teeth 18 where there is more heatable gear tooth material. As a result, the gear teeth tips 22 do not heat more rapidly to a higher temperature compared to the gear teeth bases 54 to reduce the inductive heating at the gear teeth tips 22.

[0025] A radially extending slot 56 extends from the outer edge 32 of the inductor ring 12 toward the tip 70 of each inductor tooth 48. Advantageously, the radial slots 56 force the electric current closer to the gear teeth 18 being hardened, thus increasing the efficiency of the inductor ring 12.

[0026] A dielectric material layer 58, 60, such as a ceramic material, is fixed to both planar sides 34, 36 of the inductor ring 12. The layers 58, 60 of dielectric material prevents the inductor ring planar sides 34, 36 from contacting an electrically conductive material that can provide a short circuit for electricity flowing through the inductor ring 12. In the embodiment disclosed herein, the dielectric material layers 58, 60 are formed as an integral part of the annular cooling jacket 14 and quenching ring 16. However, the dielectric material layers 58, 60 can be fixed to

the inductor ring planar sides 34, 36 independent of the cooling jacket 14 and quenching ring 16 without departing from the scope of the invention. The dielectric material 58, 60 can be the same material, or different, depending upon the application.

[0027] Referring to Figs. 1-4, the annular cooling jacket 14 preferably from a dielectric material such as a ceramic, and is fixed to one of the planar sides 34 of the inductor ring 12. The cooling jacket 14 includes passages 66, as is known in the art, through which coolant is circulated. The coolant circulates through the passages 66 in the cooling jacket 14 to maintain the inductor ring 12 at a desired temperature.

[0028] The annular quenching ring 16 is preferably formed from a dielectric material, such as a ceramic, and is fixed to the other planar side 36 of the inductor ring 12. The quenching ring 16 includes passages 68, as is known in the art, which terminate at orifices 62 at a radially inwardly facing edge 64 of the quenching ring 16. Coolant exhausts from the quenching ring 16 through the orifices 62 and sprays onto the gear teeth 18 being hardened in accordance with a predetermined inductive heat/quench cycle to provide the desired hardness and hardened depth. Of course, the cooling jacket 14 and quenching ring 16 can be formed from a conductive material that is spaced from the inductor ring 12 by a layer of dielectric material without departing from the scope of the material.

[0029] In use, gear teeth 18 forming part of a gear having twenty-four radially spaced teeth formed from a medium carbon steel, for example, such as A.I.S.I 4340, having a carbon content of between 0.38% and 0.43 % can be case hardened (i.e. heat treated) using the above disclosed apparatus 10. Preferably, the teeth are cut to a very high degree of accuracy (i.e. within tighter tolerances or tolerances allowing less deviation than required for the finished gear) prior to heat treating. For example, when tolerances for the finished gear are American Gear Manufacturers

Association (AGMA) 10 standards, the gear is machined to AGMA 11 or AGMA 12 standards prior to heat treating. Advantageously, by providing extremely accurate tooth shapes prior to inductively heat treating the teeth, such as described below, the resulting gear will not require machining after the gear has been heat treated. Once the gear is cut, it is preheated for approximately two hours at 200 °F. Although case hardening a twenty four tooth gear is disclosed, the present invention is not limited to a gear, or other work piece, having any particular number of teeth.

[0030] Following preheating, the gear 20 is inserted axially through the center of the inductor ring 12 with the ring 12 encircling the gear 20 and the gear teeth 18 interdigitating with the inductor teeth 48. In one embodiment, the inductor ring 12 is energized to a power level of approximately 22.00kw at a frequency of approximately 4.80khz to induce an electrical current in the gear teeth 18. The energized inductor ring 12 is then scanned past the gear teeth 18 at a rate of about 7.50 inches/min to heat the gear teeth 18 along the length of the gear 20. As the inductor ring 12 scans axially past the gear 20, the cooling jacket 14 maintains the inductor ring 12 at a preferred temperature. Of course, the power level, and scan rate can vary within predetermined tolerances to achieve substantially the same results. For example, the power level can vary between about 20.00 and 24.00 kw, and the scan rate can vary between about 6.5 and 8.5 inches/min without significantly affecting the resulting hardened case.

[0031] The quenching ring 16 continuously sprays coolant at a temperature of about 110 °F onto the heated gear teeth 18 of the gear 20 after the inductor ring 12 has heated and passed the gear teeth 18. When inductively heating the gear in accordance with the above power level and scan rate, the subsequent cooling of the heated gear teeth 18 by the sprayed coolant forms a hardened case of approximately 51-60 Rc at a depth of between .07-.11 inches in each gear tooth

18 having a 2.50 transverse DP. Of course, different scan rates and power levels can provide a hardened case of different depths and hardness. Preferably, quenching deflectors, or spoons, are used to properly guide the coolant to achieve the desired case hardness and depth.

[0032] Following inductively heat treating the gear, the gear is post heated for about two hours at 400 °F. Additional steps after post heating can be performed. For example, flanks of the gear can be shot-peened to increase surface durability of the flanks due to induced compressive stress. However, by heat treating the gear, as disclosed above (i.e. specific power levels and scan rates), machining the teeth to final tolerances is not required prior to using the gear, such as in assembling the gear into a machine or shipping the gear to an end user.

[0033] In another embodiment of the present invention shown in Fig. 5, a case hardening apparatus includes an inductor ring 112 especially suited for case hardening radially inwardly extending gear teeth of a gear ring. In this embodiment, the inductor ring 112 is a wafer conductor having an inner edge 130 formed at an inner diameter 126 of the inductor ring 112 and an outer edge 132 formed at an outer diameter 128 of the inductor ring 112 are joined by opposing planar sides to form an annular shape.

[0034] As in the inductor ring 12 disclosed above, a cut extending between the inner and outer edges 130, 132 splits the ring to form attachments points for electrical connectors that supply the electrical energy to the ring. One electrical connector is electrically connected to the ring on one side of the slot, and another electrical connector is electrically connected to the ring on the other side of the slot, such that the electrical energy flows through substantially the entire ring 112 from one connector to the other around the work piece being heated.

[0035] In the embodiment disclosed in Fig. 5, inductor teeth 148 extending radially outwardly from the outer edge 132 of the inductor ring 112 are received between gear teeth being

hardened. Adjacent inductor teeth 148 define a vertex 150 therebetween at the outer edge 132 of the inductor. A hole 152 drilled in the inductor ring 112 at the vertex 150 removes conductive material to prevent the tip of each gear tooth from over heating and becoming brittle. Radially extending slots 156 extending from the inner edge 130 of the inductor ring 112 toward the tip 170 of each inductor tooth 148 forces the electric current closer to the gear teeth being hardened.

[0036] As in the assembly disclosed in Figs. 1-5, dielectric material, a cooling jacket, and quenching ring can also be provided, such as described above. The quenching ring, however, exhausts quenching fluid radially outwardly onto the work piece.

[0037] While there has been shown and described what is at present considered the preferred embodiment of the invention, it will be obvious to those skilled in the art that various changes and modifications can be made therein without departing from the scope of the invention defined by the appended claims.